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Modeling the Transmission of Covid-19: Impact of Mitigation Strategies In Pre-Kindergarten-Grade 12 Public Schools, United States, 2021

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NOTE: Calculating the proportionate reduction in transmission in a school setting due to school children having a reduced probability of transmission compared to adults.

A) AGE-BASED DISTRIBUTIONS: COMMUNITY vs SCHOOL POPULATIONS:

i. Within community population distribution: Adults aged 20+ years = 80% of population; children 5-19 years = 20% of population (Source: U.S. Census Bureau)

ii. Within school population distribution: Adults aged 20+ years = 11% of population; school children = 89% of population (Main text; Methods)

B) REDUCTION IN TRANSMISSION: Proportionate level of transmission among schoolchildren compared to adults.

Assume that school children transmit 0.75 proportionate to transmission by adults, based on the following sources:

i. Age specific risk of onward transmission (expressed as susceptibility to infection)

"Specifically, relative susceptibility to infection was 0.40 (0.25–0.57) in those aged 0 to 9 years, compared with 0.88 (0.70–0.99) in those aged 60 to 69 years." (Source Davis et al.).

ii.. Age-specific probability of transmission (median (Range)

"Student to teacher without mask: 0.25 (0.010–0.68)"

"Teacher to student without mask: 0.35 (0.015–0.81)"

(Source: Pavilonis et al.)

C) ADJUSTING TRANSMISSION for changes in population age distribution: Community vs school populations:

Calculate that, if children transmit 0.75 compared to adults, then to achieve a community-wide aggregated of 2.5 persons infected per infectious person (before any interventions): adults transmit = 2.65 persons infected per infectious person and children transmit (2.65 x 0.75 = 1.99).

Aggregated levels of transmission in community and school settings are as follows:

i. Within community proportionate distribution of onward transmission: Adults (0.8 x 2.65) + Children 5 -19 years (0.2 x 1.99) = 2.52 persons infected per infectious person within community.

ii. Within school proportionate distribution of onward transmission: Adults (0.11 x 2.65) + school children (0.89 x 1.99) = 2.06 persons infected per infectious person within community.

D) SOURCES:

i : Davies NG, Klepac P, Liu Y, Prem K, Jit M; CMMID COVID-19 working group, Eggo RM. Age-dependent effects in the transmission and control of COVID-19 epidemics. Nat Med. 2020 Aug;26(8):1205-1211

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iii. U.S. Census Bureau, Population Division Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States: April 1, 2010 to July 1, 2019 (NC-EST2019-AGESEX: Accessed on 05 Feb 20221: https://www.census.gov/data/tables/time-series/demo/popest/2010s-national-detail.html

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Abstract

Background—Schools are an integral part of the community; however, congregate settings facilitate transmission of SARS-CoV-2, presenting a challenge to school administrators to provide a safe, in-school environment for students and staff.

Methods—We adapted CDC's COVIDTracer Advanced tool to model the transmission of SARS-CoV-2 in a school of 596 individuals. We estimate possible reductions in cases and hospitalizations among this population using a scenario-based analysis that accounts for: a) the risk of importation of infection from the community; b) adherence to key CDC-recommended mitigation strategies: mask wearing, cleaning and disinfection, hand hygiene, and social distancing; and c) the effectiveness of contact tracing interventions at limiting onward transmission .

Results—Low impact and effectiveness of mitigation strategies (net effectiveness 27%) results in approximately 40% of exposed staff and students becoming COVID-19 cases. When the net effectiveness of mitigation strategies was 69% or greater, in-school transmission was mostly prevented, yet importation of cases from the surrounding community could result in nearly 20% of the school's population becoming infected within 180 days. The combined effects of mitigation strategies and contact tracing were able to prevent most onward transmission. Hospitalizations were low among children and adults (less than 0.5% of the school population) across all scenarios examined.

Conclusions—Based on our model, layering mitigation strategies and contact tracing can limit the number of cases that may occur from transmission in schools. Schools in communities with substantial levels of community spread will need to be more vigilant to ensure adherence of mitigation strategies to minimize transmission.

Implications and Contributions Summary—Our results show that for school administrators, teachers and parents to provide the safest environment it is important to utilize multiple mitigation strategies and contract tracing that reduce SARS CoV-2 transmission by at least 69%. This will require training, reinforcement, and vigilance to ensure the highest level of adherence is maintained over the entire school term.

INTRODUCTION

As of January 22, 2021, >24 million cases and >400,000 COVID-19-related deaths have been reported in the United States (U.S.) since the first case was identified on January 21, 2020.[1] Recent data show that 8.5% of all cases of COVID-19 in the U.S. were among school-aged children.[2] Hospitalization and death rates in children aged 5–17 years are significantly lower than hospitalization and death rates in adults with COVID-19, suggesting that children may generally have less severe illness from COVID-19 compared to adults.[3] However, evidence indicates that children can spread the virus effectively in households and other settings.[4,5] This capacity to transmit the virus onward, even when not experiencing symptoms, to household and community members who may be more vulnerable to disease presents a challenge for in-person learning.

The access to two COVID-19 vaccines for certain groups aged >16 and >18 years offers hope for a community-wide response to COVID-19.[6,7] However, the duration of immunity provided by vaccines, as well as the effectiveness of the vaccines, still needs to be established before school administrators can evaluate impact of vaccines on reducing the risk of SARS-CoV-2 transmission in schools. Mitigation strategies that school administrators can currently deploy to prevent onward transmission of COVID-19 include mask wearing, cleaning and disinfection, hand hygiene, and social distancing.[8] Further, although out of the direct purview of most school administrators, contact tracing of persons exposed to SARS-CoV-2 provides an opportunity to promptly identify secondary COVID-19 cases and reduce the risk of onward transmission.[9]

School administrators and parents need to consider the costs and benefits of applying mitigation strategies. The costs of implementing mitigation strategies have been reported, but did not include estimates of impact.[10] To aid school administrators, staff, and parents in planning and implementing mitigation strategies to reduce the risk of school-based SARS-CoV-2 transmission, we present estimates of the number of cases and hospitalizations that could be averted by implementing mitigation strategies including contact tracing in public schools.

METHODS

We used CDC's COVIDTracer Advanced modeling tool[11] to estimate cases and hospitalizations averted due to implementation of mitigation strategies and contact tracing[a] in pre-Kindergarten–Grade 12 (preK–12) public schools. COVIDTracer Advanced is a spreadsheet-based compartmental Susceptible-Exposed-Infectious-Recovered (SEIR) epidemiological model, which illustrates the spread of a pathogen, resultant disease, and impact of mitigation strategies in a user-defined population (e.g., school). We used the tool to model within-school transmission as well as adding an adaptation to allow imported cases (i.e., infected outside of the school setting), to account for the likelihood that students and

[a]The ability of contact tracing to reduce the onward transmission of infection involves using what we know about possible exposures to enhance our ability to find and quarantine individuals who may become infectious to others. The reader should note that when we refer to contact tracing, we refer to strategies, such as frequent testing, that would enhance the ability to find and isolate infectious individuals before (or early on in) their infectious period.

staff will be infected outside of the school setting, yet attend school prior to being identified as a case and effectively isolated. We examined the potential impact of mask wearing, cleaning and disinfection,[12] hand hygiene,[13] social distancing, and contact tracing.

COVIDTracer Advanced is a deterministic model and does not produce stochastically estimated confidence intervals.[14] The inputs used for the model are presented in Table 1. Uncertainty is examined by scenario analysis, in which we estimated the impact of changing one or more input values. In the first set of scenarios, we compared 3 “no mitigation” (baseline) scenarios, examining the impact of different levels of community incidence (Table 2).We then examined 18 additional scenarios that include various school-based mitigation strategies and contact tracing. The 3 baseline scenarios illustrate the impact of different levels of SARS-CoV-2 transmission in the community (which drives an increased risk of imported cases into the school) on within-school transmission over time, before any mitigation strategies or contact tracing are implemented. The 18 additional scenarios examine the 3 levels of community transmission from the baseline scenarios combined with 2 levels of mitigation strategy effectiveness[b] and 3 levels of contact tracing effectiveness[b] (see Table 2). Scenario-specific input values can be found in Appendix A — Tables 1 and 2. All other model inputs were held constant across all scenarios; input values used are given in Table 1. Readers can download the tool (also attached here as Appendix B) and enter input values of their choosing, exploring the impact of scenarios and assumptions beyond those covered in this manuscript. Methodological details for the tool can be found in the tool’s manual (Appendix C). This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy.[c]

Epidemiological inputs and scenarios

To model the clinical progression and transmission of disease using COVIDTracer Advanced, we used the following definitions and assumptions. A “case” was defined as a person who has been exposed, infected and subsequently becomes infectious, regardless of the presence of clinical symptoms. For the first 3 days after exposure and infection, cases do not infect others. During days 4–5 post-infection, cases are pre-symptomatic but shed virus in amounts that may infect others. During days 6–14, the infected person can be symptomatic and shedding virus, albeit during days 11–14 the risk of onward transmission is relatively low but non-zero[15-17] (the complete infectivity distribution is given in Appendix A — Table 3). We assumed that approximately 40% of cases are asymptomatic during days 6–14, yet have a risk of onward transmission equal to 75% of symptomatic cases.[18]

For population size, we used an average public school population of 596 (529 students, 67 staff [8 students per staff]).[19] We assumed that schools initially had zero cases. Within-school transmission was seeded by the importation of cases from the surrounding community, after which within-school transmission can occur. For simplicity, we assumed that transmission risk in the school was equal within and between age groups, and the age

[b]We define “effectiveness” as it is used throughout this manuscript as the ability of a public health action to reduce onward transmission of disease. Note that this is not necessarily equivalent to the amount of viral particles that are blocked/eliminated (e.g., for mask wearing or cleaning/disinfecting).

[c]See e.g., 45 C.F.R. part 46, 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.

distribution of all cases (symptomatic and asymptomatic) matched the age distribution of the school population, therefore, 88% of cases occurred in students (Table 1). The risk of hospitalization in the model differ by age groups (Table 1). Transmission of cases was modeled for 365 calendar days to allow for differences in the lengths of school terms, enabling readers to assess the cases and impact of mitigation strategies and contact tracing appropriate for the number of days in their school term.

For the baseline scenarios, we examined the growth of cases over time without any reduction in transmission due to mitigation strategies or contact tracing interventions and assuming 3 levels of SARS-CoV-2 transmission in the community for case importation. We converted community incidence thresholds of 9 (low), 49 (moderate), and 99 (substantial) cases per 100,000 persons[8] into equivalent rates of 0.05, 0.29, and 0.59 imported cases per week[d], respectively (Table 1 and Appendix A — Table 4). Note that the current CDC Operational Strategy for K-12 Schools provide equivalent threshold community categories of transmission measured in terms of percent positivity of COVID nucleic acid amplification tests (NAATs).[8] We further assumed, to simplify, that all imported cases entered the school each Monday; no allowances were made for holidays. This simplification, of having each week's imported cases arrive on Mondays, will not notably alter the subsequent epidemic curve.

Intervention Scenarios

To assess the impact of mitigation strategies on reducing in-school transmission, we created 2 scenarios that reflect "low" and "high" levels of impact resulting from the combined implementation of 4 individual mitigation strategies: mask wearing[20-25], cleaning and disinfection[22], hand hygiene[22,26], and social distancing[26] (Table 2 and Appendix A —Table 2). Three factors were considered for calculating the combined effectiveness of these mitigation strategies on SARS-CoV-2 transmission: efficacy[e] of individual mitigation strategies, compliance (over an entire school term), and how mitigation strategies interact. Estimates of efficacy for each mitigation strategy were based on published data;[20-26] the degrees of compliance were assumed as no data about adherence with individual mitigation strategies in school settings are available. Finally, we assumed a non-linear effect of simultaneous implementation of individual mitigation strategies, such that each additional mitigation strategy provided a decreasing marginal impact on reducing SARS-CoV-2 transmission (Appendix A— Figure 1).

To evaluate the impact of contact tracing on in-school transmission, we generated three contact tracing scenarios using the following model inputs: the average number of days from exposure-and-infection to when cases are isolated and contacts quarantined; the percentage

[d]COVIDTracer Advanced possess the capacity to calculate onward transmission in units less than one person. In practical terms, a value of imported-into-school case of less than 1 (e.g., 0.03 cases/ week) indicates a risk less than 1 (i.e., certainty) but greater than zero risk. The probabilities over time are not cumulative. The risk of importation is essentially "reset" each week. A consistent risk of importation of, say, 0.03 cases/ per week indicates that school administrators must assume that at any week, an imported case might appear in the school, creating a risk of onward transmission with the school.

[e]Efficacy of a mitigation strategy is used in this text to refer to the upper bound on "effectiveness" (that is, the reduction in onward transmission of disease provided by a single mitigation strategy at maximum possible adherence.) We then define that the "net effectiveness" of mitigations strategies is a function of efficacies, adherence levels, and interaction effects (see Appendix A—Table 1 for further details).

of cases isolated and contacts quarantined; (referenced as S1, S2, S3, see Appendix A— Table 2). We also built two mitigation strategy scenarios (low or high impact – Appendix A— Table 1). Then, for each of the 3 levels of community incidence (Table 2), we built 6 scenarios using a combination of the 3 contact tracing scenarios and 2 mitigation scenarios (Table 2).

Hospitalizations

To determine the severity of COVID-19 cases averted in the community by implementing strategies in schools, we calculated hospitalizations averted by each mitigation strategy and contact tracing scenario. COVID-19-specific medical codes (ICD-10-CM codes U07.1 and B97.29)[f] were applied to the Premier Healthcare Database to estimate rates of COVID-related hospitalizations (i.e., general ward only, ICU without ventilator use, ICU with ventilator use) among 3 age groups: 0–17 years, 18–64 years, and ≥65 years, (Table 1).[27] The database includes hospital discharge data from >1,030 hospitals and 8 million annual inpatient records in the United States.

RESULTS

Without any mitigation strategies or contact tracing, the lowest level of case importation from the community will lead to >90% of the school population having been infected within ≤100 days of the school term (Table 2 and Figure 1, "Base Case" scenarios). For comparison, the highest rate of case importation results in approximately 91% of the school population having been infected (Table 2), with nearly all cases occurring within ≤70 days of the school term (Figure 1).

Implementation of mitigation strategies and contact tracing at low levels of effectiveness for each (Table 2, e.g., low impact of mitigations + S1) provided only a slight reduction in cases, ranging from 75–77% of the school population becoming infected between days 0–180, depending on the level of community incidence. When community incidence was low, notable control of school-based transmission could be achieved with a "high" impact of contact tracing (S3: quarantining of contacts such that 70% of secondary cases are prevented from transmitting disease by the 6th day after exposure, including asymptomatic cases) even when the impact of mitigation strategies are low (Table 2: low impact of mitigations + S3). However, as community incidence increases, "high" mitigation strategy effectiveness combined with "medium" contact tracing effectiveness (S2: quarantining of contacts such that 50% of secondary cases are prevented from further transmitting the disease by the 6th day after exposure, including asymptomatic cases) or better is required to keep total infections to less than 10% of the school's population. The results in Table 2 are extended in Appendix A — Table 5 to include estimates of cases and hospitalizations broken down into 3 age groups (017, 18-64, and 65+ years).

[f]Patients with ICD-10-CM code of U07.1 (COVID-19) were restricted to discharge months April-July 2020 and admission months January – November 2020; patients with ICD-10-CM code of B97.29(Other coronavirus as the cause of diseases classified elsewhere) were restricted to discharge months March – April 2020 and admission months February – April 2020.

The lowest number of cases occurred when the combined effectiveness of mitigation strategies and contact tracing was ≥69%. Under these conditions, even assuming a substantial level of community incidence (99 cases/100,000 population), there would be ≤53 cases (9.0% of the school population) (Table 2: high impact of mitigations + S2 or S3), a significant portion of which were imported cases (27–56%, see Appendix A — Table 6). Despite these cases attending school while infectious, the combined effects of mitigation strategies and contact tracing were able to prevent most onward transmission from these imported cases.

Hospitalizations Averted

Figure 2 shows the number of hospitalizations averted by each scenario compared to the baseline scenarios. The number of hospitalizations was equivalent to 0.4% of the school population in the worst-case scenario (low impact of mitigation) (Appendix A — Table 6) . Patterns of averted hospitalizations followed the patterns seen for reduction in cases between scenarios, such that implementation of mitigation strategies and contact tracing interventions with a combined effectiveness of ≥69% led to nearly all hospitalizations being averted.

Sensitivity Analysis

In addition to the multiple scenarios examined for a school of 596 students and staff (Figure 1), all the scenarios were re-estimated for a school of 1,473 students and staff (the largest average public school size) (Appendix A, Figure 1).[19] The larger sized schools generated proportionately larger numbers of cases for each scenario, but the interpretations are the same. Further, we examined multiple scenarios when community transmission was high (250 cases/100,000 population). Under these conditions, a combined effectiveness for mitigation strategies and contact tracing of 69% or greater would result in ≤112 cases (18.8% of the school population) (Appendix A Table 7: high impact of mitigations + S2 or S3), a significant portion of which were imported cases (28–58%, see Appendix A, Table 6).

DISCUSSION

Officials in many school districts across the United States are deciding whether to reopen for in-person learning and considering approaches for the 2021–22 school year. To aid school administrators, staff, and parents in the planning and implementation of strategies to reduce the risk of SARS-CoV-2 transmission in preK–12 schools, we present estimates of the number of cases and hospitalizations averted by implementing mitigation strategies and contact tracing using the COVIDTracer Advanced modeling tool. In this study, we assumed a school population of approximately 600 students and staff and found that without implementing mitigation strategies or contact tracing, regardless of the level of community transmission, almost all the school population will be expected to become a COVID-19 case in ≤100 days. Combining low impact mitigation strategies (~14% effectiveness) and limited contact tracing (~13% effectiveness) results in ~40% of the school population becoming cases in <4 months (448-454 cases). Combining high impact mitigation strategies and robust contact tracing (≥69%), even in communities with substantial COVID-19 incidence (99/100,000), results in only 0.4%–9% of the school population becoming a case (~2–53 cases) in 130 days. Furthermore, a sizeable portion of these cases (25–57%, see Appendix

A — Table 6) would be imported into the school from the surrounding community, with mitigation strategies preventing most onward transmission within the school. The low level of hospitalizations is a result of the majority of the school population being comprised of students, where persons aged ≤17 years are less likely to have a clinical presentation that requires hospitalization.[3]

Findings from this study reinforce the importance of ensuring high and consistent adherence to implemented mitigation strategies that lead to consistent early isolation of cases in schools. This study also lends evidence to previous reports using empirical data indicating that pre-K–12 public schools can reopen when there is low transmission in the community if they develop and adhere to recommended COVID-19 mitigation strategies. This model offered 21 different scenarios to accommodate for different school situations and mitigation employment across the United States. Zimmerman et al.[28] examined 11 school districts with nearly 100,000 students/staff open for 9 weeks of in-person instruction, tracking secondary transmission of SARS-CoV-2; each case was independently adjudicated for community or within-school acquisition by local health departments. Furthermore, among 17 rural Wisconsin schools, reported student mask-wearing was high, and the COVID-19 incidence among the school population was lower than in the in the community.[29] The schools in both studies enforced mitigation strategies including masking, physical distancing, and hand hygiene, resulting in minimal clusters of COVID-19 cases and low rates of secondary transmission in schools, and did not cause a larger community infection burden. Schools should implement concurrent preventive measures and adjust these strategies based on community transmission data.[30] Schools may not be able, for a variety of reasons, to implement one or more of the interventions examined in this study. In such situations, to ensure that schools have the safest possible environment, schools will have to find ways to increase the effectiveness of the interventions that are deployed.

Successfully operating schools during the COVID-19 pandemic requires sufficient resources to implement and sustain effective mitigation strategies.[10] Implementing and monitoring adherence to recommended mitigation strategies can reduce risk for SARS-CoV-2 transmission in educational settings that remain open for in-person learning and reduce the spread of disease within the school and community.[31] To support implementation of mitigation strategies, CDC developed tools to allow schools to monitor and evaluate the implementation of mitigation strategies, including examples of evaluation questions, indicators, and suggested data sources to understand the impact of these strategies in schools.[32] Additional resources help schools plan, prepare, and respond to COVID-19, thereby helping to protect students and staff and slowing community spread of SARS-CoV-2.[33]

Combined with other mitigation measures, contact tracing has effectively limited SARS-CoV-2 transmission in various settings.[34,35] Successful contact tracing in schools requires timeliness and school administration and parents' engagement to encourage participation and cooperation. Identifying and communicating with persons exposed to SARS-CoV-2 (close contacts) should be prioritized because of the potential for transmission that can occur in schools. Although challenges to contact tracing have been reported despite aggressive efforts by health departments,[36] contact tracing in schools is feasible because most in-school contacts can be identified, reached and recommended to quarantine.

Our findings are subject to several limitations. First, we assumed homogenous mixing (that is, that contact between any two individuals occurs randomly and with equal probability) and constant onward transmission for the duration of a school term, both within the community and translating to the resultant risk of importation into a school. Community-wide incidence likely fluctuates over the course of a school term, altering the risk of importation of cases into a school. We partially mitigated the impact of this limitation having a wide range of risk of importation (Table 2). Second, the scenarios of the effectiveness of the mitigation strategies, both individual and sum totals (Appendix A — Table 1), may not directly reflect actual field experiences. Nevertheless, the ranges in these scenarios provide at least partial mitigation. Third, we note that some data indicates that school children have a reduced probability of approximately 0.75 of transmission compared to adults.[37,38] Adjusting the baseline value of new infections per case (R0 = 2.5: Table 1) for a school population in which 89% are children, gives an in-school value of 2.0 (see Appendix A). This 20% reduction in transmission would cause a proportionate reduction in estimates of cases averted. Additionally, we note that COVIDTracer Advanced does not explicitly incorporate testing for COVID-19. Diagnostic testing does not directly reduce the transmission of disease, but rather offers opportunities for improving the ability to identify infectious cases in a more timely manner, irrespective of symptomatic presentation. Diagnostic testing, however, can result in isolation of those found to be infected and quarantine of those found to be in close contact, and can reduce transmission. To this end, the user can implicitly account for the impact of testing by modifying the inputs for contact tracing effectiveness to reflect the change in times to isolation, in the proportion of cases found and isolated, etc. Further, the potential impact of testing for screening (to prevent the introduction of a case into a school; i.e., "testing at the entry gate") can be estimated by proxy by comparing the differences between substantial and low community levels of incidence. Lastly, we do not account for transmission that may have been caused by school-acquired infections transmitting outward into the community, which could produce a cycle of transmission between these two populations that may prolong / exacerbate continued generation of new cases. We included multiple (albeit, constant) levels of community incidence to partially account for this concern.

No single mitigation strategy implemented in schools with in-person attendance can control within-school transmission of SARS-CoV-2. While the impact of vaccination in school staff that meet the vaccination criteria and in certain children aged >16 and >18 years will add to the impact of these other critical mitigation strategies in the near future, this study suggests that implementation of and strict adherence to key mitigation strategies as recommended in CDC School Mitigation Guidelines (mask wearing, cleaning and disinfection, hand hygiene, social distancing, and contact tracing) can result in a decreased transmission rate in schools compared to the baseline. Additionally, the following public health efforts provide additional layers of COVID-19 prevention in schools: testing to identify individuals with SARS-CoV-2 infection to limit transmission and outbreaks, and vaccination for teachers and school staff and community members as soon as supply allows. When schools implement testing combined with key mitigation strategies, they can detect new cases to prevent outbreaks, reduce the risk of further transmission, and protect the school population. A layered approach using all available evidence-based measures has shown success in preventing within-school transmission.[39] Schools provide numerous benefits beyond education, including facility-based services such as school meal programs, academic intervention support, afterschool services, and social, physical, behavioral, and mental health services. Schools play a critical role for children and their families; therefore every reasonable effort should be made to keep public schools safely open. To enable safer in-person learning, schools should implement and practice layered mitigation strategies to protect students and staff from COVID-19, which would reduce school transmission of COVID-19[40] and reduce the burden on the health care system.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Disclaimer:

The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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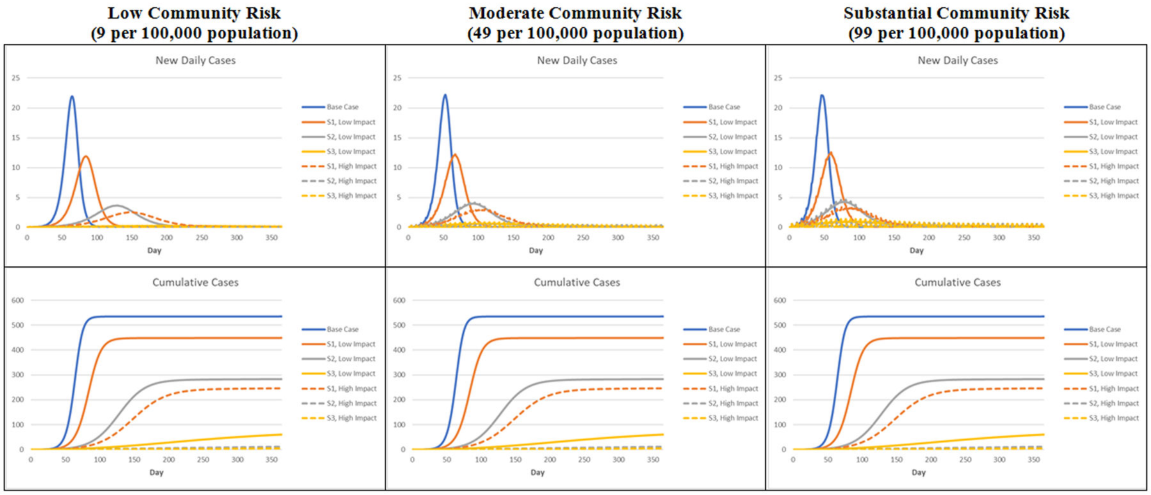

Figure 1: Daily number and cumulative total of school cases under three scenarios of community incidence and six intervention scenarios[a,b,c,d]

[a] School size of 529 students and 67 staff.

[b] Cases refer to both symptomatic and asymptomatic cases. Asymptomatic cases represent 40% of all cases and transmit at a rate of 75% of that of symptomatic cases (Table 1).

[c] Note that cases per day and cumulative total cases include the imported cases – represented by the "spikes" seen in some of the plots of daily cases. Effective application of mitigation strategies, particularly contact tracing, should discover those cases and reduce or even prevent onward transmission from such introduced cases.

[d] Legend: Base Case = no interventions applied; Low and high impact refers to two scenarios of 4 non-pharmaceutical interventions (mitigation strategies) (mask wearing, cleaning + disinfection, hand hygiene, social distancing), combined to provide 13.6% and 36% net effectiveness, respectively (Table 2); S1, S2 and S3 refer to three contact tracing scenarios, which provide 12.8%, 32.6% and 45.6% effective reduction in transmission. For each combination of mitigation strategy scenario and contact tracing scenario, an estimate of net effectiveness is calculated by summing the two estimates (e.g., low impact mitigation strategy scenario of 13.6% + contact tracing scenario S3 of 45.6% = net effectiveness of 59.2%, see Table 2).

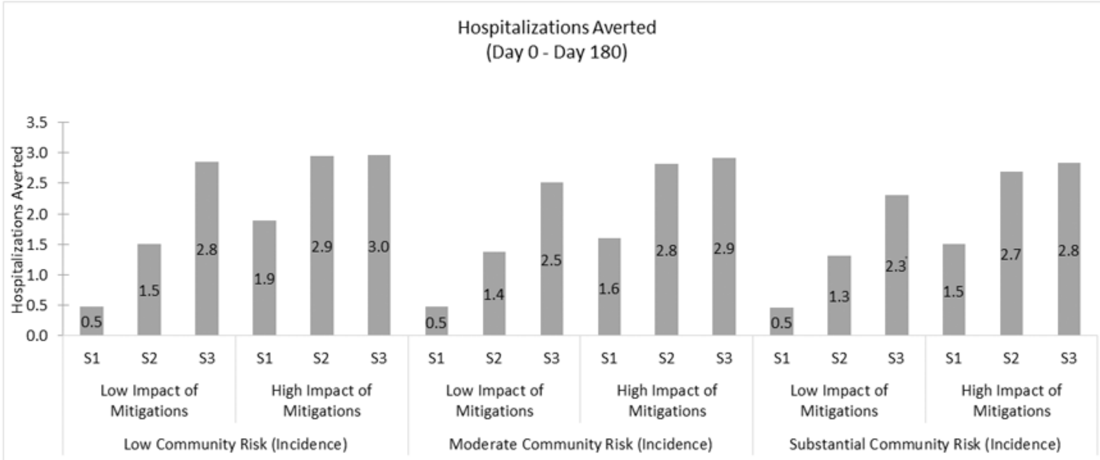

Figure 2: Total hospitalizations averted relative to the baseline scenario (no interventions) under three scenarios of community incidence and six intervention scenarios[a]

[a] Legend: Base Case = no interventions applied; Low and high impact refers to two scenarios of 4 non-pharmaceutical interventions (mitigation strategies) (mask wearing, cleaning + disinfection, hand hygiene, social distancing), combined to provide 13.6% and 36% net effectiveness, respectively (Table 2); S1, S2 and S3 refer to three contact tracing scenarios, which provide 12.8%, 32.6% and 45.6% effective reduction in transmission. For each combination of mitigation strategy scenario and contact tracing scenario, an estimate of net effectiveness is calculated by summing the two estimates (e.g., low impact mitigation strategy scenario of 13.6% + contact tracing scenario S3 of 45.6% = net effectiveness of 59.2%, see Table 2).

Table 1:

COVIDTracer[a] Model: Epidemiological parameters, values, and sources.

Parameter	Default Value	Source
Infected but not yet infectious period	3 days	CDC COVID-19 Pandemic Planning Scenarios[18]
Pre-Symptomatic and Contagious (infectious) period	2 days	He et al.[16,17] Ferreti et al [15]
Symptomatic and Contagious (infectious) period	9 days	He et al.[16,17] Ferreti et al[15]
New infections per case (R0)	2.5	CDC COVID-19 Pandemic Planning Scenarios[18]
% of cases that are asymptomatic	40%	CDC COVID-19 Pandemic Planning Scenarios[18]
Infectiousness of asymptomatic cases (relative to symptomatic cases)	75%	CDC COVID-19 Pandemic Planning Scenarios[18]
Imported cases per week (by community risk scenario[b])		
9 per 100,000	0.05	Assumed[c]
49 per 100,000	0.29	
99 per 100,000	0.59	
% of cases by age group[d]		
0-17 years	88%	Assumed[d]
18-64 years	6%	
65+ years	6%	
% of all cases admitted for hospital care		Blaisdell et al[41] Wu et al[42]
0-17 years	0.21%	
18-64 years	2.17%	
65+ years	4.12%	
% of hospitalized cases requiring ICU[e] care		
0-17 years	33.20%	
18-64 years	29.90%	
65+ years	35.00%	
% of ICU[e] cases requiring mechanical ventilation		
0-17 years	17.39%	
18-64 years	16.24%	
65+ years	21.10%	

[a] COVIDTracer Advanced is a spreadsheet-based compartmental Susceptible-Exposed-Infectious-Recovered (SEIR) epidemiological model, which illustrates the spread of a pathogen, resultant disease, and impact of mitigation strategies in a user-defined population (e.g., school).

[b] Community risk scenarios are based on levels of community incidence of COVID-19 and define the risk of importing a case into a school, and potentially initiating a within-school chain of transmission. The scenarios assume homogenous mixing.

[c] The assumed community levels of incidence result in the listed number of cases imported into a school of 596 students and staff. For simplicity, we assumed that, each week, imported cases were introduced into the school on Mondays (Appendix A — Table 4).

[d] Assumed that % of cases by age groups was equal to the distribution of the population among age groups. This, in turn, assumes that because of preponderance of students relative to staff, that risk of transmission within the school is equal within and between age groups.

[e]ICU = Intensive Care Unit

Table 2:

Total cases and hospitalizations by scenario[a]

Community Risk (Incidence: Cases per 100,000)	*Impact of School Mitigations*	*Impact of Contact Tracing*	**Net Effectiveness of School Mitigations**	**Net Effectiveness of Contact Tracing**	**Combined Effectiveness of Mitigation Strategies + Contact Tracing**	**Total Cases (Day 0 - Day 180) #**	**Total Cases (Day 0 - Day 180) % of pop.**	**Total Hospitalizations (Day 0 - Day 180) #**	**Total Hospitalizations (Day 0 - Day 180) % of pop.**
Low Community Risk (Incidence: 9 per 100,000)	**Base Case (no interventions)**					534	*90.3%*	3.0	*0.5%*
	Low Impact of Mitigations	**S1**	13.6%	12.8%	**26.4%**	448	*75.6%*	2.5	*0.4%*
		S2	13.6%	32.6%	**46.2%**	264	*44.6%*	1.5	*0.2%*
		S3	13.6%	45.6%	**59.2%**	24	*4.0%*	0.1	*0.0%*
	High Impact of Mitigations	**S1**	36.0%	12.8%	**48.8%**	194	*32.8%*	1.1	*0.2%*
		S2	36.0%	32.6%	**68.6%**	6	*0.9%*	0.0	*0.0%*
		S3	36.0%	45.6%	**81.6%**	2	*0.4%*	0.0	*0.0%*
Moderate Community Risk (Incidence: 49 per 100,000)	**Base Case (no interventions)**					535	*90.4%*	3.0	*0.5%*
	Low Impact of Mitigations	**S1**	13.6%	12.8%	**26.4%**	450	*76.1%*	2.5	*0.4%*
		S2	13.6%	32.6%	**46.2%**	288	*48.7%*	1.6	*0.3%*
		S3	13.6%	45.6%	**59.2%**	83	*14.0%*	0.5	*0.1%*
	High Impact of Mitigations	**S1**	36.0%	12.8%	**48.8%**	249	*42.0%*	1.4	*0.2%*
		S2	36.0%	32.6%	**68.6%**	28	*4.7%*	0.2	*0.0%*
		S3	36.0%	45.6%	**81.6%**	13	*2.2%*	0.1	*0.0%*
Substantial Community Risk (Incidence: 99 per 100,000)	**Base Case (no interventions)**					536	*90.6%*	3.0	*0.5%*
	Low Impact of Mitigations	**S1**	13.6%	12.8%	**26.4%**	454	*76.6%*	2.5	*0.4%*
		S2	13.6%	32.6%	**46.2%**	301	*50.8%*	1.7	*0.3%*
		S3	13.6%	45.6%	**59.2%**	123	*20.8%*	0.7	*0.1%*
	High Impact of Mitigations	**S1**	36.0%	12.8%	**48.8%**	268	*45.2%*	1.5	*0.3%*
		S2	36.0%	32.6%	**68.6%**	53	*8.9%*	0.3	*0.0%*
		S3	36.0%	45.6%	**81.6%**	26	*4.4%*	0.1	*0.0%*

[a]Legend: Base Case = no interventions applied; Low and high impact refers to two scenarios of 4 non-pharmaceutical interventions (mitigation strategies) (mask wearing, cleaning + disinfection, hand hygiene, social distancing), combined to provide 13.6% and 36% net effectiveness, respectively (Table 2); S1, S2 and S3 refer to three contact tracing scenarios, which provide 12.8%, 32.6% and 45.6% effective reduction in transmission. For each combination of mitigation strategy scenario and contact tracing scenario, an estimate of net effectiveness is calculated by summing the two estimates (e.g., low impact mitigation strategy scenario of 13.6% + contact tracing scenario S3 of 45.6% = net effectiveness of 59.2%, see Table 2)